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# Research on Atmospheric Attenuation of Infrared Radiation

Howard T. Betz

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# Research on Atmospheric Attenuation of Infrared Radiation

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Geophysics Research Directorate
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### FOREWORD

This is the technical report on infrared transmission measurements through fog made at Arcata, California, during September and October 1959 under Contract No. AF 19(604)-5877. This report includes material presented in LAS-TN-E173-5; discussion included in paper presented in AMRAC meeting in Seattle, Washington, on 22 July 1960; and additional reduced transmission data (for which no particle data are available).

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## ABSTRACT

This report summarizes the results of a measurement program conducted at Air Force Cambridge Research Center Fog Site at Arcata, California. The purpose of the Arcata fog experiment was (1) to collect data permitting a test of the applicability of Junge's law of the distribution of particle size as a consistent phenomenon of fogs and (2) to verify the predicted values of transmission based upon particle size a stribution. The experimental data presented tend to corroborate both Junge's law for particle size distribution and the theory for attenuation using this law.

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#### 1. INTRODUCTION

The principal purpose of this study is to determine the atmospheric attenuation of infrared radiation in a slant path of 5,000 to 40,000 feet in the wavelength range of 1 to 4 microns.

The program was amended to include (i) the determination of the infrared spectral transmission and attenuation through long paths of fog and (2) correlation of the observed attenuation with the density and size distribution of the fog particles and other pertinent physical parameters.

This report summarizes the results of a measurement program conducted at Air Force Cambridge Research Center, Fog Site at Arcata, California.

#### 2. PURPOSE OF EXPERIMENT

The purpose of the Arcata fog experiment was twofold:

(i) To collect data permitting a test of the applicability of Junge's law of the distribution of particle size as a consistent phenomena of fogs which states that

$$n(r) = cr^{-p} , \qquad (1)$$

in which n(r) = concentration of particles per unit radius interval; <math>r = radius of particles (microns); and c, p = constants for Junge's law.

(2) To verify the predicted values of transmission based upon particle size distribution [1,2].\*

Total scattering at  $\lambda$  due to above distribution is

$$\sigma = \int \pi r^2 K\left(\frac{r}{\lambda}\right) n(r) dr$$
,

in which  $K(r/\lambda)$  is the scattering coefficient, or

$$\sigma = c\pi \int_{\mathbf{r}_0}^{\mathbf{r}_1} r^{(2-p)} K\left(\frac{\mathbf{r}}{\lambda}\right) d\mathbf{r}$$

in which  $\mathbf{r}_0$  and  $\mathbf{r}_1$  are the smallest and largest radii, respectively, for which Junge's law is valid in a particular fog..

\*Numbers in brackets refer to entries in the List of References at the end of this report.

By change of variable to  $(r/\lambda)$ , and neglecting the lower limit,

$$\sigma = c \pi \lambda^{(3-p)} \int_0^{r_1/\lambda} \left(\frac{r}{\lambda}\right)^{(2-p)} K\left(\frac{r}{\lambda}\right) d\left(\frac{r}{\lambda}\right) . \tag{2}$$

The values for  $K(r/\lambda)$  have been tabulated [3,4]. The integral in Eq. (2) can, in general, be integrated numerically and tables of  $\sigma$  as a function of  $\lambda$ , p, c, and  $r_4$  can be devised. The parameters p, c, and  $r_4$  can be measured experimentally.

#### 3. EXPERIMENTAL PROCEDURE

To test the above relations, the experimental work was divided into two phases:

- (1) Direct measurement of particle size distribution.
- (2) Measurement of the fog transmission as a function of wavelength.

The particle size measurement was made with the Cambridge Research Center's cloud particle counter constructed by the Armour Research Foundation. This device counts particles and classifies them according to size by the light scattered from individual particles. Particles are classified into six sizes: 1 to 2, 2 to 4, 4 to 8, 8 to 16, 16 to 32, and larger than 32 microns in diameter.

Wherever possible the particle count data and transmission measurements were taken concurrently, and the particle counter was located adjacent to the optical path

Spectral measurements were made with essentially that equipment used by Kurnick et. al. [1]. The source, located in a small trailer, was a carbon arc with a 12-1/2 inch, f/5 collimator. The receiver was a Perkin-Elmer double-pass monochromator with a 12-1/2 inch, f/5 collector, and was located in a semi-trailer 200 yards from the source. The interval chopper of the monochromator was modified to give an 80-cps chopping rate. The detector was a 0.1- by 0.1-mm thermistor bolometer. Bandwidth of the amplifier was 20 cycles centered at 80 cps. The final record was made on an x-y recorder with the detector output on the x-axis and monochromator wavelength drum position on the y-axis. Using a sodium-chloride prism the instrument scanned from 1.5 to 12 microns in approximately 4 minutes. The slit width was varied to maintain a reasonable power level on the detector; i.e., the radiant power on the detector was maintained within a factor of 100 to 1. Figure 1 shows the actual variations in power level.

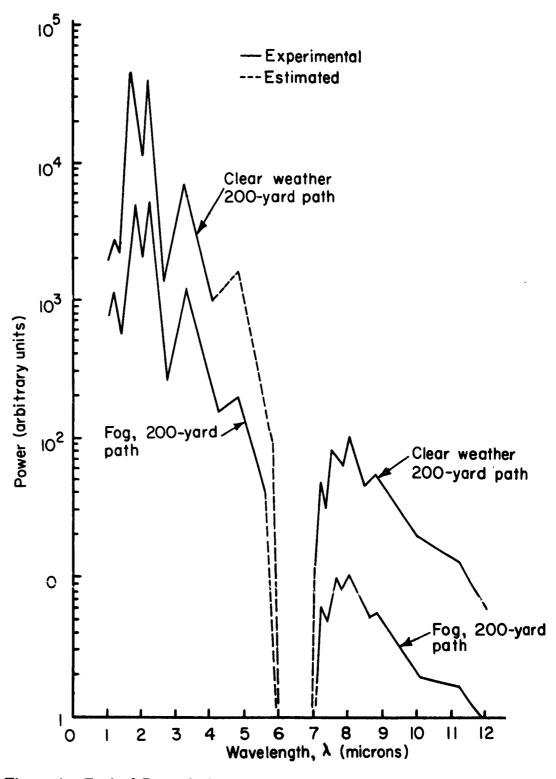


Figure 1. Typical Record of Normalized Spectrum of Carbon Arc Observed through a 200-yard Path in Clear Weather and Fog.

#### 4. DISCUSSION OF RESULTS

The results of the particle size measurements are shown in Table 1 for fog data taken on 16 October 1959. (The particle counter was delivered on 12 October, but it was not until 16 October that the instrument was operating satisfactorily; hence, this is the only day for which reliable data are available. Transmission data and other parameters such as wind direction are given for all days in Tables 2 and 3. The measurements of visibility were taken at the National Bureau of Standard's visibility range about 500 yards from the infrared transmission path.)

The values for particle size are given in terms of the number of particles per cubic centimeter for size intervals of 0.5 to 1.0, 1.0 to 2.0, 2.0 to 4.0, 4.0 to 8.0, and 8.0 to 16.0 microns in radius. The columns are labeled with the mean radius of each interval; i.e., 0.75, 1.5, 3, 6, and 12 microns.

Junge's law, Eq. (1), was checked by plotting  $n(r) \Delta r$ , the number of particles per unit volume in radius interval  $\Delta r$ , against the mean particle radius in the interval on a logarithmic scale (see Figure 2). The negative slope of this curve is the value of p. Since a straight line can be drawn through the points in Figure 2, Junge's law applies to this fog.

An attempt was made to correlate the transmission observed through fog with Eq. (2) using the values of p, c, and r obtained from the analysis of the aerosol data. This equation, in principle, gives the absolute transmission as a function of wavelength. However, it is not directly useful for several reasons:

- (1) The transmission T is dependent on c. (Note that ln(1/T) = σL, where L is the path length.) Since sampling was made at a fixed point near the path, considerable variation in concentration may exist. Hence, correlation between the overall transmission and concentration is doubtful.
- (2) The use of a carbon arc which required readjustment at intervals may easily have disturbed the alignment of the system. Therefore, the absolute value of the measured transmission may not be accurate. The relative values for various wavelengths during a single run are not affected; thus, the shapes of the curves on a log plot of transmission are accurate.

An alternative approach was used to make the correlation. Equation (3), derived by differentiation from Eq. (2), is independent of the value of c. It is related to the shape of the experimental curve of log log reciprocal transmission vs. log  $\lambda$  by Eq. (4).

$$\frac{d(\ln \sigma)}{d(\ln \lambda)} = (3 - p) - \frac{r_1^{(3-p)} K(\frac{r_1}{\lambda})}{\int_0^{r_1/\lambda} (\frac{r}{\lambda})^{(2-p)} K(\frac{r}{\lambda}) d(\frac{r}{\lambda})} .$$
 (3)

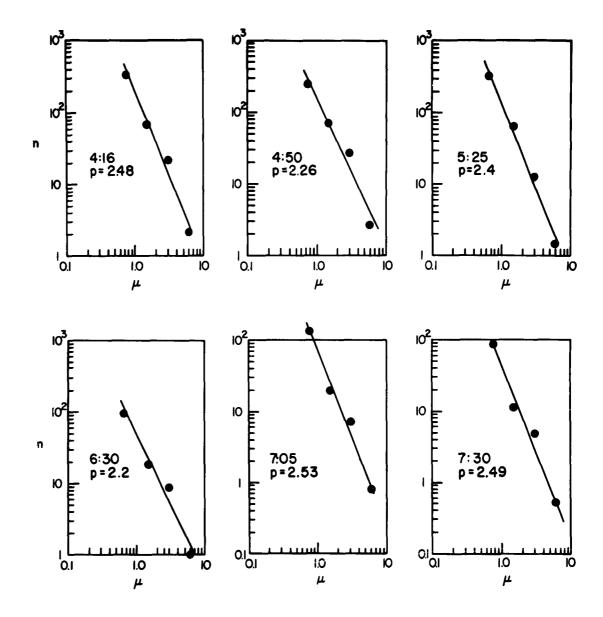


Figure 2. Selected Plots of n(r) vs r for Fog on the Morning of 16 October 1959.

$$\frac{d(\ln \sigma)}{d(\ln \lambda)} = \frac{d\left(\ln \ln \frac{1}{T}\right)}{d(\ln \lambda)} = \frac{d\left(\log \log \frac{1}{T}\right)}{d(\log \lambda)} \tag{4}$$

The values of p and  $r_4$  should be the same throughout the fog. The second term on the right in Eq. (3) is of interest. For p>3 and a particular  $r_4$ , this term is dependent on p and only slightly dependent on  $\lambda$  (or  $r_4/\lambda$ ). For decreasing values of p<3, this term develops a "ripple" becoming increasingly dependent on  $r_4/\lambda$ . Since  $r_4$  is at best an approximate value, a smoothed value should be used for  $[d(\ln \sigma)]/[d(\ln \lambda)]$ . The resulting smoothed value becomes positive for  $2.2 (in the region <math>(r_4/\lambda) >> 1$ ). In this range of  $r_4/\lambda$ , the slope of the transmission data is zero or slightly positive (note dotted lines in Figure 3). For  $(r_4/\lambda) < 1$  (Rayleigh scattering),  $[d(\ln \sigma)/[d(\ln \lambda)]$  is always strongly negative and one should expect a rapid increase in transmission (decrease in  $\ln \ln 1/T$ ). Such a change to increasing transmission occurs in the experimental data at about 10 microns, again, see Figure 3. The most to be said about  $r_4$  from the experimental particle data is that it lies between 8 and 16 microns.

Therefore, within the limits of accuracy of the equipment, the experimental data tends to corroborate both Junge's law for particle size distribution and the theory for attenuation using this law.

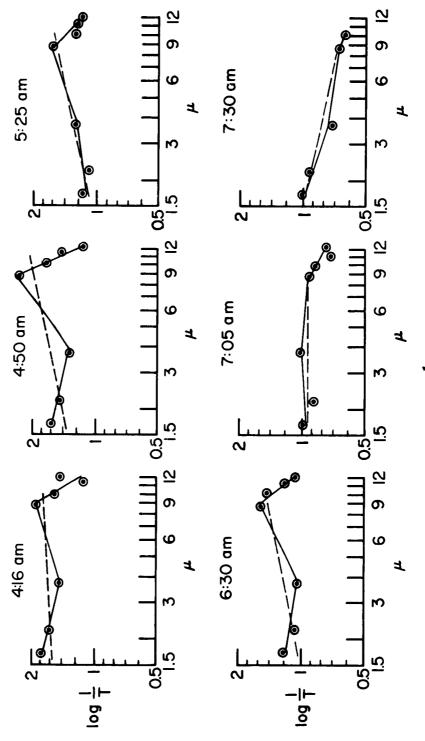


Table 1. Particle Size and Transmission Measured in Fog on 16 October 1959 at Arcata, California

Time	Numbe	Number of Particles per cm <sup>3</sup> per Unit Radius Interval n(r)*	cles per nterval	$\frac{\text{cm}^3}{\text{n}(r)^*}$ pe	r Unit	۵				$\operatorname{Log}\left(\frac{1}{T}\right)$			
	r= 0.75µ	r= 1.5µ	r= 3µ	r= 6µ	$r = 12\mu$	,	$\lambda = 1.7\mu$	$\lambda = 2.2 \mu$	λ=3.7μ	λ = 8 · 8μ	λ = 10μ	$\lambda = 11.2\mu$	$\lambda = 12\mu$
4:00 A.M.	275	71.5	21.2	1.59	0.000022	2.48	1.58	1.47	1.43	1.74	1.64	1.21	1.17
4:10 A.M.	!	:	;	;	:	!	1.70	1.62	1.28	1.70	1.60	1.33	1.28
4:16 A.M.	332	67.7	21.2	2.12	0.0088	2.48	1.77	1.60	1.49	1.89	1.52	1.20	1.46
4:35 A.M.	332	60.5	31.8	2.68	0.0048	2.44	ļ	;	1.08	2.05	1.52	1.33	1.28
4:45 A.M.	314	57	23	5.6	0.003	2.45	1.66	1.50	1.50	2.04	1.85	1.35	1.48
4:50 A.M.	237	2.99	25.9	5.6	0.0013	2.26	1.60	1.46	1.29	2.30	1.52	1.41	1.15
5:00 A.M.	373	9.69	25.3	1.49	0.003	2.39	1.72	1.64	1.59	1.96	1.60	1.51	1.28
5:10 A.M.	184	53.0	21.6	2.11	0.0008	2.15	1.73	1.55	1.56	2.05	1.70	1.51	1.28
5:15 A.M.	250	50.0	12.5	1.56	0.003	29.2	1.52	:	1.28	2.05	1.47	1.33	1.16
5:25 A.M.	319	64.4	12.8	1.42	8000:0	2.4	1.17	1.10	1.26	1.58	1.24	1.21	1.17
5:30 A.M.	287	62.2	13.2	1.8	0.0035	2.4	1.34	1.11	1.18	1.70	1.31	1.20	1.28
5:40 A.M.	213	38.3	7.91	1.12	0.0004	2.64	1.24	1.09	1.00	1.44	1.32	1.12	0.996
5:50 A.M.	592	59.4	14.9	1.66	0.0015	2.44	1.47	1.42	1.30	1.66	1.32	1.12	!
6:00 A.M.	254	52.4	8.56	1.01	9000.0	5.69	1.15	1.04	1.14	1.51	1.41	1.26	1.06
6:10 A.M.	236	48.7	8.11	0.89	0.0009	3.00	1.48	1.40	1.41	1.57	1.55	1.17	:
6:20 A.M.	139	36.3	15.2	2.10	6000.0	2.07	1.02	0.958	1.00	1.16	1.15	0.946	0.924
6:30 A.M.	95.1	18.5	8.81	1.02	0.00044	2.20	1.22	1.09	1.08	1.57	1.48	1.22	1.07
6:40 A.M.	178	36.9	8.52	0.923	0.00263	2.56	0.793	992.0	0.743	1.06	1.03	0.872	0.801
6:45 A.M.	168	32.3	9.12	1.12	0.0026	2.42	9.876	0.787	0.681	1.07	0.924	0.688	0.757
7:05 A.M.	130	19.3	7.12	0.788	0.0013	2.53	0.987	0.893	1.01	906.0	0.860	0.721	0.757
7:20 A.M.	100	11.2	4.48	0.588	0.0013	1.99	:	:	0.743	-	:	;	!
7:30 A.M.	84.9	11.1	4.90	0.506	0.0004	2.49	1.01	0.916	0.711	0.657	0.625	0.167	! !
7:45 A.M.	34.5	4.24	3.48	0.499	0.000.0	27.22	0.951	0.854	0.857	0.991	1.022	0.886	0.866
"Clear" 2:15 P.M.	23	3.45	0.78	0.056	0.000	!	0.00	0.00	0.00	0.00	0.00	0.00	00.00
				1									1

\*Note that n(r) is an average value derived by measuring the concentration of particles in radius interval  $\Delta r$  and dividing by the radius interval.

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Experimental Transmission and Particle Count in Fog on 16 October 1959. Table 2.

Velocity Direction (degrees)  3			Per ce	ent of	Trans	Per cent of Transmission,	o u		Particles.	Per	centa	te of F	Percentage of Particles		Visible	Wind	Wind	Temperature
3.4         3.7         8.8         1.0         11.2         1.2         1.4         8.8         1.6         1.6         1.0 <th>Time</th> <th></th> <th>Wave</th> <th>lengt</th> <th>I at at</th> <th>Micro</th> <th></th> <th></th> <th>per cm</th> <th>Å</th> <th>stweer</th> <th>Note</th> <th>d Size</th> <th></th> <th>Transmis-</th> <th>Velocity</th> <th>Direction</th> <th>(degrees</th>	Time		Wave	lengt	I at at	Micro			per cm	Å	stweer	Note	d Size		Transmis-	Velocity	Direction	(degrees
2.4         5.3         1.6         6.8         265         54         27         16         2.4         0.0067         19         3           2.4         5.3         2.5         4.7         5.3		1.7	2.2	3.7	8.8	9		12		1-2μ	2-4µ	_	8-16μ	16-32µ	cent)		(degrees)	centigrade)
3.4         3.7         1.8         2.3         6.1         6.8         2.0         2.4         6.4         0.0067         19         3           2.4         3.1         1.8         2.3         6.3         3.5         2.2         2.4         15         0.005         11         4           2.5         3.2         1.3         3.5         2.2         2.4         15         3.0         0.0128         11         4           3.2         3.4         4.7         5.3         3.03         55         2.0         21         3.0         0.0128         10         3.5           3.2         3.4         0.5         3.0         4.7         5.3         3.0         5.3         3.0         4.7         5.0         2.2         3.4         4.7         7.0         2.4         4.5         3.0         0.0043         1.2         2.2         2.2         3.0         0.0043         1.2         2.2         2.2         4.7         7.0         2.4         4.7         2.7         2.4         4.7         2.0         0.0043         1.2         2.2         2.2         4.7         2.0         0.0043         1.2         2.2         2.2         4.7 </td <td></td> <td></td> <td>,</td> <td></td> <td></td> <td>,</td> <td></td> <td></td> <td></td> <td></td> <td>,</td> <td>,</td> <td></td> <td>-,</td> <td>;</td> <td>•</td> <td></td> <td></td>			,			,					,	,		-,	;	•		
2, 4         5, 3         2, 0         2, 5         4, 7         5, 3	4:00 A. M.		*:		0	د. ع			697	4	3	10	<b>4</b> .7	0.0067	13	n	190	11
2.5         3.6         3.9         6.3         3.5         2.82         59         24         45         3.0         0.0025         11         4            8.0         0.9         3.0         4.7         5.3         3.03         55         20         21         3.6         0.0128         10         3.5           3.2         3.1         0.89         4.4         4.5         3.3         270         58         27         12         3.6         0.0043         22         2         2         0.0049         3.2         2         2         4.7         2.0         0.0048         4.7         2         2         0.0048         2         2         2         0.0048         3.2         2         2         2         0.0048         3.7         2         2         2         2         2         0.0048         3.7         2         2         2         2         2         2         3.0         0.0188         3         2         2         2         3.0         0.0048         3         2         2         2         4.3         0.0048         3         2         2         2         4.3         0.0048         3	4:10 A. M.		2.4	5.3	2.0	2.5	4.7		:	;	:	;	;	:	;	!	:	11
8.0         0.0         3.0         4.7         5.3         303         55         20         21         3.6         0.0128         10         3.5           3.2         3.1         0.0         3.4         4.5         3.3         270         58         21         17         3.8         0.009         12         2           3.5         5.1         0.5         3.0         3.9         7.0         247         48         27         2.2         0.0043         22         2           2.2         2.6         1.1         2.5         3.1         5.3         3.46         60         24         3.0         0.0188         22         2.2         4.3         0.0043         2.5         2         2.2         4.3         0.0048         2         2         2.5         4.3         0.0048         2         2.5         4.3         0.0048         2         2         2         2         2         2         2         2         2         2         2         2         2         2         2         2         3         2         2         2         2         2         2         2         2         2         2 <td>4:16 A. M.</td> <td></td> <td>2.5</td> <td>3.2</td> <td>1.3</td> <td>3.0</td> <td></td> <td></td> <td>282</td> <td>59</td> <td>77</td> <td>15</td> <td>3.0</td> <td>0,0025</td> <td>11</td> <td>4</td> <td>150</td> <td>11</td>	4:16 A. M.		2.5	3.2	1.3	3.0			282	59	77	15	3.0	0,0025	11	4	150	11
3.2         3.4         0.8         1.4         4.5         3.3         270         58         21         4.7         3.8         0.0043         12         2           3.5         5.1         3.0         3.0         3.0         2.47         48         27         21         4.2         0.0043         22         2           2.3         2.6         1.1         2.5         3.1         5.3         316         59         22         6.0         0.0048         27         2.5           2.8         2.0         0.9         3.4         4.7         7.0         208         60         24         12         0.0048         27         2.5           4.0         5.3         2.0         2.2         4.7         7.0         208         60         24         12         3.0         0.0048         27         2.5         3.0	4:35 A. M.	;	;	8.0	6.0	3.0	4.7		303	55	22	21	3.6	0.0128	10	3,5	115	11
3.5         5.1         0.5         3.0         3.0         7.0         247         48         27         21         4.2         0.0443         22         2           2.3         2.6         1.1         2.5         3.1         5.3         316         59         22         1.6         2.2         0.0078         14         2.5           2.8         2.8         2.9         3.1         5.3         196         47         27         22         4.3         0.0018         27         2.5           2.9         3.4         4.7         7.0         2.08         60         24         12         4.3         0.0018         27         2.5           3.0         5.5         2.6         5.7         6.1         6.2         2.2         4.0         0.0018         27         2.5           4.0         5.5         2.6         5.7         6.4         5.3         2.0         2.7         2.0         0.00149         2.7         2.5           8.1         5.0         5.2         5.2         5.2         5.2         5.0         0.00248         2.7         2.5         2.2           8.2         5.2         5.2	4:45 A. M.		3.2	3.1	0.89	1.4	4.5		270	58	2.1	17	3.8	0.009	12	7	135	11
2.8         2.6         1.1         2.5         3.1         5.3         316         59         22         4.0         0.0048         14         2.5           2.8         2.9         2.0         3.1         5.3         196         47         27         22         4.3         0.0018         27         2.5            5.3         0.9         3.4         4.7         7.0         208         60         24         12         3.0         0.0148         31         2.5           8.0         5.5         2.6         6.3         5.3         259         60         26         13         0.01479         32         2.5           8.0         5.5         2.6         6.0         24         12         3.0         0.0148         3.1         2.5           8.1         5.6         1.0.1         1.66         64         23         9.5         2.7         0.0024         2.5         2.5           9.2         1.0.2         4.8         7.6         1.0.1         1.66         64         23         9.5         2.7         0.0024         2.5         2.5           9.2         1.2         2.0         2.2	4:50 A. M.		3.5	5.1		3.0		7.0	247	48	22	24	4.2	0.0043	22	7	100	11
2.8         2.9         2.0         3.4         5.3         496         47         27         22         4.3         0.0018         27         2.5            5.3         0.9         3.4         4.7         7.0         208         60         24         4.2         3.0         0.0148         31         2.5           8.0         5.2         6.3         6.3         6.3         5.3         2.5         60         26         10.0         0.01479         33         2.5         30         0.01479         32         2.5         30         2.5         30         0.01479         32         2.5         30         2.0         0.01479         32         2.5         30         2.5         30         0.01479         32         2.5         30         2.5         30         0.01479         32         2.5         30         0.01479         32         2.5         30         0.01479         32         2.5         30         0.01479         32         2.5         30         0.01479         32         2.5         30         0.01479         32         2.5         30         0.01479         32         2.5         30         0.01479         30	5:00 A. M.		2.3	2.6	1.1	2.5			316	59	22	16	2.2	0,0078	14	2.5	115	11
5.3         0.9         3.4         4.7         7.0         208         60         24         4.2         3.0         0.0418         31         2.5           8.0         5.2         2.6         2.6         2.6         2.6         4.0         0.00268         30         2.5           7.7         6.6         2.0         4.9         6.3         5.3         239         60         26         4.1         3.0         0.04179         32         2.5           8.2         10.0         3.6         4.8         7.6         10.1         166         64         23         2.7         0.00241         2.2         2.5           8.2         10.0         3.6         4.8         7.6         10.1         166         64         23         2.7         0.00241         2.7         2.5            9.2         1.2         4.8         2.01         63         2.6         4.9         4.0         6.0         2.6         4.0         0.0025         3.0         2.5         2.5         3.0         2.5         3.0         2.5         3.0         2.5         3.0         3.0         3.0         3.0         3.0         3.0         3.	5:10 A. M.		2.8	2.8	6.0	2.0	3.1	5.3	196	47	27	77	4.3	0.0018	27	2.5	09	11
8.0         5.5         2.6         5.7         6.1         6.8         267         62         25         10         2.6         0.00268         30         2.5           7.7         6.6         2.6         4.9         6.3         5.3         239         60         26         11         3.0         0.01479         32         2.5           8.2         10.0         3.6         4.8         7.6         10.1         166         64         23         9.5         2.7         0.00211         21         2.5         2.5         3.9         2.7         0.00211         21         2.5         3.5         3.6         2.8         2.6         12         3.0         0.0025         3.6         2.5         3.0         0.0025         3.0         2.5         3.0         2.5         3.0         0.0025         3.0         2.5         3.0         0.0025         3.0         2.5         3.0         0.0025         3.0         2.5         3.0         0.0025         3.0         2.5         3.0         0.0025         3.0         2.5         3.0         0.0025         3.0         2.5         3.0         0.0025         3.0         2.5         3.0         0.0025         <	5:15 A. M.		1	5.3	6.0	3.4	4.7	7.0	208	09	77	12	3.0	0.0118	31		325	11
7.7         6.6         2.0         4.9         6.3         5.3         239         60         26         41         3.0         0.01479         32         2.5           8.2         10.0         3.6         4.8         7.6         10.1         166         64         23         9.5         2.7         0.0021         21         2.5           3.8         5.0         2.2         4.8         7.5          228         58         26         12         3.0         0.0025         36         2.5           9.2         7.3         3.1         3.9         5.5         8.8         201         63         26         1.9         0.0025         36         2.5           4.0         3.9         5.5         8.8         201         48         26         20         0.0025         30         2.5           4.0         3.0         3.0         3.2         2.0         4.8         4.8         2.6         2.7         0.0048         2.5         2.5           4.0         4.0         4.1         4.8         4.8         2.4         4.8         4.8         2.6         4.0         0.0048         2.5         2.5     <	5:25 A. M.		8.0	5,5	2.6	5,7		6.8	267	29	25	10	2.6	0.00268	30	2,5	270	11
8.2         10.0         3.6         4.8         7.6         10.1         166         64         23         9.5         2.7         0.0021         21         2.5           3.8         5.0         2.2         4.8         7.5          228         58         26         12         3.0         0.0052         36         2.5           4.0         3.0         2.2         4.8         201         63         26         1.9         0.0025         30         2.5           4.0         3.9         5.5         8.8         201         4.9         0.0048         20         2.5           4.0         3.0         6.9         7.1         11.3         11.9         145         48         25         2.1         5.8         0.0048         20         2.5           4.0         1.0         6.0         7.1         11.3         11.9         145         48         25         2.1         2.0         0.0048         20         2.5         2.5         2.0         2.5         2.5         2.5         2.2         2.5         2.0         0.0044         20         2.5         2.5         2.6         0.0044         40         3.0 <td>5:30 A. M.</td> <td></td> <td>7.7</td> <td>9.9</td> <td>2.0</td> <td>4.9</td> <td></td> <td>5,3</td> <td>239</td> <td>09</td> <td>56</td> <td>11</td> <td>3.0</td> <td>0.01179</td> <td>32</td> <td>2.5</td> <td>Shifting</td> <td>11</td>	5:30 A. M.		7.7	9.9	2.0	4.9		5,3	239	09	56	11	3.0	0.01179	32	2.5	Shifting	11
3.8         5.0         2.2         4.8         7.5          228         56         12         3.0         0.0052         36         2.5           9.2         7.3         3.1         3.9         5.5         8.8         201         63         26         8.5         2.0         0.0025         30         2.5           4.0         3.9         2.7         3.8         6.8          188         63         26         9.0         1.9         0.0048         25         2           4.0         1.0         6.9         7.1         11.3         11.9         145         48         25         21         5.8         0.0048         20         2.5         2           4.0         1.0         1.0         1.0         0.0048         20         0.0048         20         2.5         2	5:40 A. M.			10.0	3.6	4.8	9	10.1	166	49	23	9.5	2.7	0.00211	21	2,5	Variable	11
9.2         7.3         3.1         3.9         5.5         8.8         201         63         26         8.5         2.0         0.0025         30         2.5         2           4.0         3.9         2.7         2.8         6.8          188         6.3         26         9.0         1.9         0.0018         25         2           4.0         3.9         2.7         2.8         6.8          188         54         20         0.0048         20         2.5         2         3         3         3         3         3         3	5:50 A. M.			5.0	2.2	4.8		;	228	58	97	12	3.0	0.0052	36	2.5	Variable	11
4.0         3.9         2.7         2.8         6.8          188         63         26         9.0         1.9         0.0018         25         2           41.0         10.0         6.9         7.1         11.3         11.9         145         48         25         21         5.8         0.0048         20         2.5         1           8.2         8.3         2.7         3.3         6.1         8.5         88         54         21         20         0.004         40         3.0         2.5         1         1         3.0         3.0         3.0         40         3.0         3.0         40         3.0         3.0         40         3.0         40         3.0         40         3.0         40         3.0         40         3.0         40         3.0         40         3.0         40         3.0         40         3.0         40         40         41.5	6:00 A. M.		9.5	7.3	3.1	3.9		8.8	201	63	97	8.5	2.0	0.0025	30	2.5	45	11
41.0         10.0         6.9         7.1         11.3         11.9         145         48         25         21         5.8         0.004         20         2.5           8.2         8.3         2.7         3.3         6.1         8.5         88         54         21         20         5.8         0.004         40         3.0           17.0         18.0         8.8         9.4         13.4         15.8         142         63         23         12         2.6         0.0074         42         1.5         3.0           16.3         21.0         8.8         14.2         14.2         60         23         13         2.6         0.0074         42         1.5         1.5           16.3         21.0         8.0         14.2         14.0         60         23         13         2.0         1.5	6:10 A. M.		4:0	3.9	2.7	2.8	6.8	;	188	63	92	9.0	4.9	0.0018	25	7	02	11
8.2         8.3         2.7         3.3         6.1         8.5         88         54         21         20         5.8         0.004         40         3.0           17.0         18.0         8.8         9.4         13.4         15.8         142         63         23         12         2.6         0.0074         42         1.5         2         1.5	6:20 A. M.		11.0	0.01	6.9	7.1	11.3	11.9	145	48	25	21	5.8	0.0048	20	2.5	105	11
17.0         18.0         8.8         9.4         13.4         15.8         142         63         23         12         2.6         0.0074         42         1.5           16.3         21.0         8.5         11.8         20.5         17.5         140         60         23         13         3.2         0.015         46         1.5           12.         14.6         17.7         21.3         29.8	6:30 A. M.			8.3	2.7	3,3	6.1	8.5	88	54	21	20	5.8	0.00€	40	3.0	06	11
16.3         21.0         8.5         11.8         20.5         17.5         140         60         23         13         3.2         0.015         46         1.5	6:40 A. M.	16.0	17.0	18.0	8.8	9.4		15.8	142	63	23	12	5.6	0.0074	45	1.5	250	11
12.8         9.8         12.4         13.9         12.1         13.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5         10.0         17.5	6:45 A. M.		16.3	11.0	80 10			17.5	140	09	23	13	3.2	0.015	46	1,5	190	11
42.8         9.8         12.4         13.8         19.0         17.5         10.0         44         3.1         0.010         44         3.0            18.0           73         69         15.4         6.9         3.2         0.0143         60         3.5           42.1         19.5         22.6         23.7         68.0          65         47         15         3.1         0.0054         74         3.9           44.0         13.5         22.6         23.7         44         23         6.6         0.0054         74         3.9           44.0         13.9         13.0         13.6         3.2         57         14         23         6.6         0.000         25         2           45.0         10.0	6:55 A. M.		:		14.6	۲.		29.8	;	;	;	:	1		1	:	1	11
18.0            73         69         15.4         6.9         3.2         0.0143         60         3.5           12.1         19.5         22.6         23.7         68.0          65         17         15         3.1         0.0054         74         3.9           14.0         13.5         13.6         32         57         14         23         6.6         0.000         25         2           1.0          0.7         0.95         1.5         2.0             2.4         3.9           10<	7:05 A. M.				12.4	80		17.5	102	2	19	77	3.1	0.010	‡	3.0	135	11
12. 1     19.5     22. 6     23. 7     68.0      65     65     17     15     3.1     0.0054     74     3.9       14.0     13.9     10.2     9.5     13.0     13.6     32     57     14     23     6.6     0.000     25     2       1.0      0.7     0.95     1.5     2.0          25     2       100     100     100     100     100     160 <t< td=""><td>7:20 A. M.</td><td></td><td>1</td><td>18.0</td><td>;</td><td>-</td><td>;</td><td>i</td><td>73</td><td></td><td>15.4</td><td>6.9</td><td>3.2</td><td>0.0143</td><td>09</td><td>3,5</td><td>150</td><td>11</td></t<>	7:20 A. M.		1	18.0	;	-	;	i	73		15.4	6.9	3.2	0.0143	09	3,5	150	11
14.0      0.7     0.95     1.5     13.6 <t< td=""><td>7:30 A. M.</td><td></td><td>12. 1</td><td>19.5</td><td>22.6</td><td></td><td>68.0</td><td>:</td><td>99</td><td>99</td><td>11</td><td>15</td><td>3.1</td><td>0.0054</td><td>2</td><td>3.9</td><td>98</td><td>11</td></t<>	7:30 A. M.		12. 1	19.5	22.6		68.0	:	99	99	11	15	3.1	0.0054	2	3.9	98	11
4.0      0.7     0.95     1.5     2.0          2.4       400     400     400     400     46     72.4     22     4.9     .25     0.000     95     5	7:45 A. M.		14.0	13.9	10.2	.5		13.6	32	57	1,	23	9.9	000.0	25	7	160	11
400         100         100         100         100         100         100         16         72.4         22         4.9         .25         0.000         95         5	7:50 A. M.	0, 68					1.5	2.0	;	1		:	:	ł	;	2.4	135	11
	2:15 P.M.	100	100		_	100	100	100	16	72.4	22	4.9	. 25	000.0	9.5	ĸ	300	11

\*Particles were counted for a period of 3 minutes beginning at each time listed. Total number of particles counted varied from 4000 to 90,000 in the 3-minute interval.

Table 3. Experimental Infrared Transmission through Fog.

Wind *	Direction				
Wind	Velocity			ბოოე 20 10 10 10 10 10 10 10 10 10 10 10 10 10	2.5
Visible	ransmission	(Per cent)		22422444444222	96
		12		no measurable transmission	100
no		11.2	October 1959	no measurable transmission	100
ansmissi n Micron		10	3 Octo	no measurable transmission	100
Per cent of Transmission Wavelengths in Microns	9	8.8		no measurable transmission	100
Per c		2.2		0.80 0.17 0.03 0.04 0.002 0.01 0.01 0.01 0.01 0.01 0.01 0.0	100
		1.7		0.70 0.26 0.19 0.03 0.01 0.01 0.01 0.01 0.02 0.00 0.00 0.00	100
	Time			4:35 P. M. 4:45 P. M. 4:50 P. M. 5:20 P. M. 7:15 P. M. 7:25 P. M. 7:25 P. M. 7:45 P. M. 7:45 P. M. 8:30 P. M. 8:30 P. M. 9:50 P. M. 9:50 P. M. 10:15 P. M.	4 Oct. 59 3:30 P.M.

\*Wind direction can be obtained from the National Bureau of Standards installation at Arcata, California.

Table 3 (continued)

Wind *	7110011011					***									•														
Wind	retocaty			5*9	z,	4	3.5		10	6	8.5	11.5	10	œ	6.5	5	4	13.5	4.5	3.5	3.5	2.5	6.5	7.5	6.5	7.5	10.0	2.5	1.5
Visible Transmission	(Per cent)	(2000 - 1		85	82	96	91		•	52	56	72	40	35	36	10	9	9	1	30	52	20	10	80	70	80	80	96	94
	,,	12		150	09	70	100		5.0	52	53	95	6.7	13	6.7	10.1	6.7	8.4	52	25	39	26	139	168	143	120	196	105	100
on, s	,	11.2	October 1959	140	71	77	100	October 1959	7.3	88	7.1	139	23	21	7.2	12.5	9.4	11.5	25	09	89	82	162	193	143	126	205	130	100
er cent of Transmission, Wavelengths in Microns	9	10	8 Oct	190	57	100	100	9 Oct	6.4	57	29	39	21	38		9.6	7.1	10.6	32	74	55	98	159	172	125	129	195	108	100
nt of Tra engths in		8.8		150	73	81	100		10	1	100	106	17		^1					5.9									
Per cer Wavel		2.2		160	140	100	100			93	93	170	44	123	2.7	9.5	2.4	2.1	2.3	52	88	;	94	200	167	162	195	150	100
		1.7		150	120	93	100			85	92	170	41	108	2.6	9.7	2.0	1.8	2.0	23	92	1	74	180	155	152	169	134	100
	Time			9:10 A.M.	9:25 A.M.	Ŕ	Ą.		7:30 A.M.	Ř		8:40 A.M.	Ŕ	Ä		Ÿ	ď	Ŕ	Ķ	Ä	ġ.	Ä	Ą	Š	Ä	Ä	Ř	σ,	ď.

Table 3 (continued)

Wind	Direction*													108	180	162	144	139	54	99	54	95	171	147	135	216	167	176	202	300
Wind	Velocity	,		;	ļ	;	;	t í	1	;	1	1		ĸ	•	5.5	•	•	•	•	•	•	•	•	•	•	3.0	•	•	2
Visible	Transmission	(Per cent)		ហ	8	4	:	34	40	06	65	96		0	0	0	0	0	0	0	7	7	0	0	0	0	0	0	0	95
		12	6			4.7	•	46	49	121	87	100	6	r	10	m	ea	LSI	ır	ab	le	tı	a	ns	m	is	si	on		100
ion,	su	11.2	October 195			2.0	•	51	99	104	74	100	October 195	r	10	m	ea	LSI	ır	ab	le	tı	rai	ns	m	is	si	on		100
Transmission,	avelengths in Microns	10	12 Oc			9.0		37	39	46	120	100	14 Oc	r	10	m	ea	1.51	ır	ab	le	tı	ra	ns	m	is	si	on		100
cent of Tr	elengths	8.8		1.7	2.8	0.92	•	23	35	64	29	100		n	10	m	ea	su	ıra	ab	le	tr	aı	18:	m	is	sic	on		100
Per c	Wav	2.2				1.8	•	•			26			•	•	•	•	•	•	•	•	•	•	•	•	•	0.010	•	•	100
		1.7			•	1.7	•	•	ö	54	9	100		0.007	0.12	0.019	0.013	0.016	0.106	0.052	0.213	0.065	0.008	0.009	0.008	0.032	0.007	0.011	0.010	100
	Time	)		7:25 A.M.	:35 A.	Ķ	:55 A.	:02	:15 A.	:25 A.	:30	:40 A.			ď,	2:05 A.	2:30 A.	Ā	2:55 A.	Ą.	Ķ	Ķ	¥	Ŕ	Ķ	Ą	Ŕ		:25 A.	16 Oct. 59 2:15 P. M.

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UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED
AD- AF Cambridge Research Center, Bedford, Mass. RESEARCH ON ATMOSPHERIC ATTENUTION OF INFRARED RADIA- TION, by Howard T. Betz. Dec 1960. 13 pp.incl. illus. (Proj. 4991; Task 49910) LAS-TN-E173-10 (AF 19(604)-5877)	This report summarizes the results of a measurement program conducted at Air Force Cambridge Research Genter Fog Site at Arcata, California. The purpose of the Arcata fog experiment was (1) to collect data permitting a test of the application of the condet of the collect data permitting a test of the applications.	bility of Junge's law of the distribution of particle size as a consistent phenomenon of fogs and (2) to verify the predicted values of transmission based upon particle size distribution. The experimental data presented tend to corroborate both Junge's law for particle size distribution and the theory for attenuation using this law.	
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